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HIGH-EFFICIENCY CORE TECHNOLOGY

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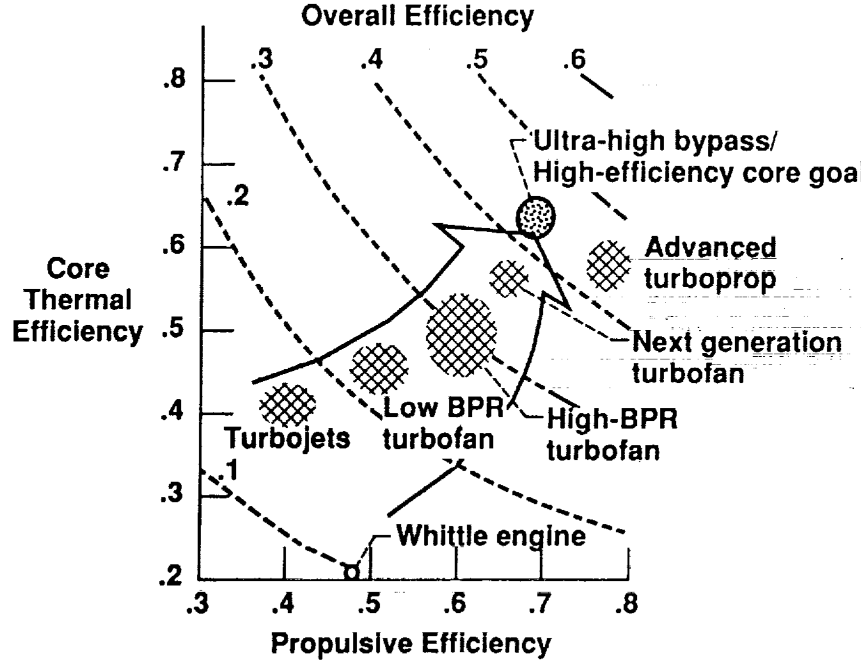
Studies were undertaken to determine the potential benefits from implementing aircraft turbine engine core technology well beyond that being developed for the next generation of long-haul subsonic transport engines (i.e., entry into service date of 1993). These core improvements, projected for year 2010 technology, include the use of very high-pressure-ratio cycles, advanced lightweight materials with minimal cooling requirements, and improved component efficiencies. The studies indicate that a large improvement is possible with engines using these advanced cores as compared to the current turbine engine designs. This paper reports on the results of the studies and identifies the key challenges to achieving the predicted improvements in performance.

Civil Engine Efficiency Trends



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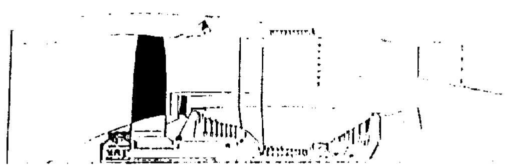
Large gains in turbine engine overall efficiency have been made since the first turbojets were introduced. Recent advances such as high-bypass turbofans and the advanced turboprop have resulted largely in improvements in propulsive efficiency. The goal of the current set of studies was to emphasize the core in order to investigate the potential of improving the thermal efficiency over that of the next generation turbofan. A shift in the efficiency trend is shown by the arrow in the figure.

High-Efficiency Core Study

Objective: assess benefits of advanced high-efficiency cores for large and small aircraft turbine engines and identify key technologies

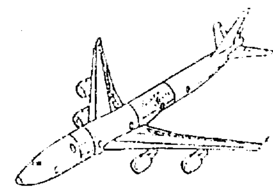
Engine



Scope:
- OPR 50 - 100
- FPR 1.3 - 1.5
- 2 & 3 Spools
- Direct & geared fans
- In-line & off-axis cores
- Year 2010 Tech. readiness

Contractors:
- General Electric
- Pratt & Whitney
- Allison

Mission



- 4-engine aircraft
- Speed, Mach 0.85
- Range, 5000 nm
- Passengers, 500

Assessment criteria:
- Fuel burned
- DOC

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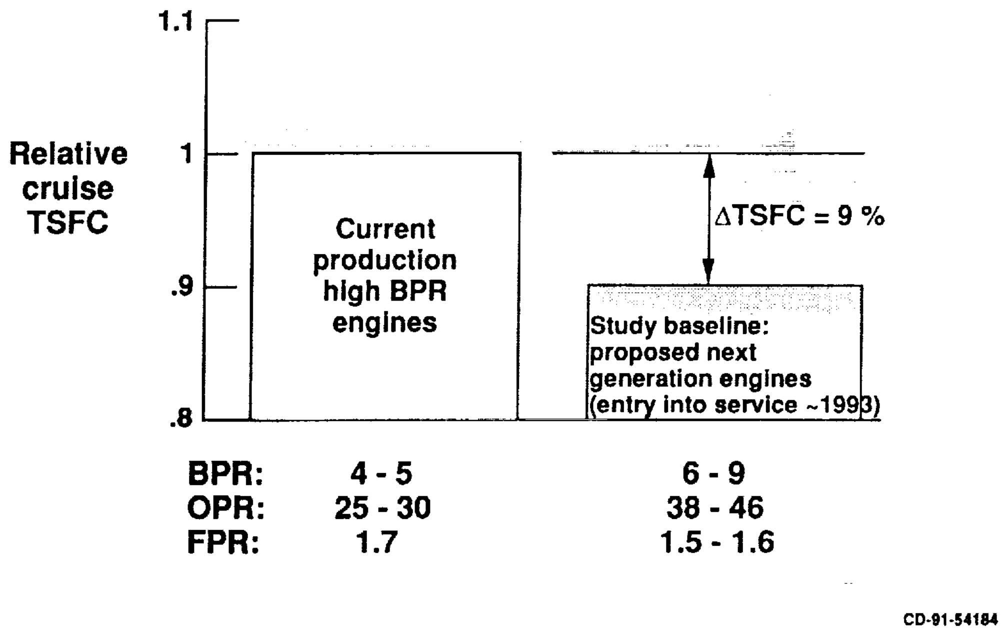
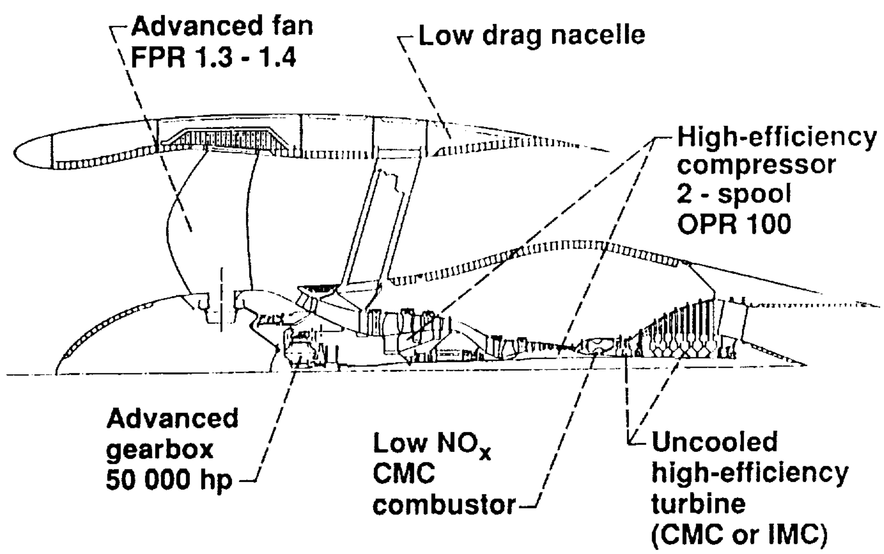
Studies were undertaken to assess the potential benefits of advanced high-efficiency cores, to develop a preliminary mechanical design for assessment of concept feasibility, and to determine the key technologies required for implementation. Engines with overall pressure ratios (OPR's) of 50 to 100, fan pressure ratios (FPR's) of 1.3 to 1.5, and uncooled or minimally cooled hot sections were evaluated. Direct and geared fans were considered as well as in-line and off-axis core configurations. In all cases, the bypass ratios were optimized to take advantage of the high specific power cores which result from the high pressure and temperature conditions. Year 2010 technology readiness was assumed for all engine technologies. General Electric and Pratt & Whitney assessed large engines of about 50 000 pounds of thrust suitable for a 500-passenger advanced subsonic aircraft. The advanced engines were evaluated in terms of both fuel burned and direct operating cost (DOC) improvements for this aircraft relative to the baseline engine. In addition, Allison studied an advanced, high-efficiency, 8000-shaft horsepower (SHP) turboshaft engine suitable for high-speed rotorcraft. Only engine performance was evaluated in this study.

Subsonic Transport Baseline Engine Definition



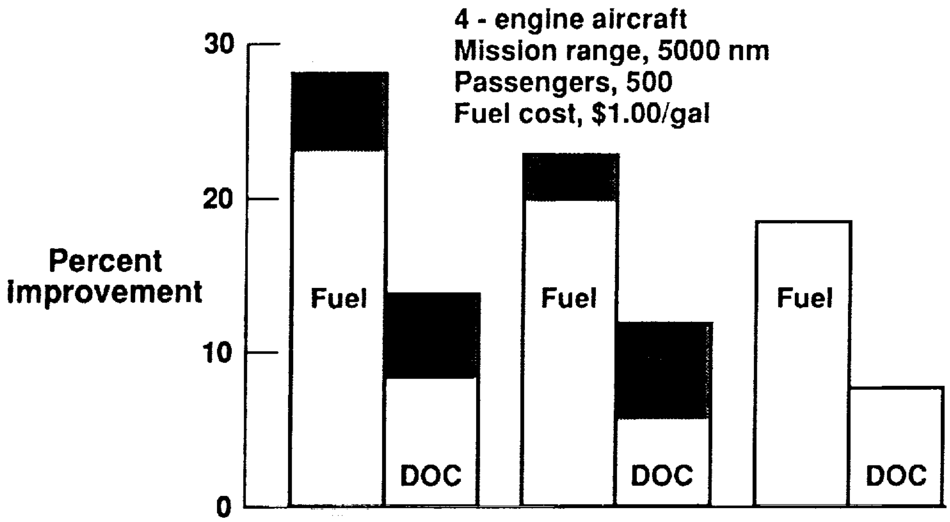
The baseline engine chosen for the large-engine studies was a proposed next-generation turbofan engine with an entry into service date of 1993. This baseline engine has approximately 9 percent lower cruise thrust specific fuel consumption (TSFC) than current production high-bypass-ratio (BPR) engines. A comparison of cycle performance for the baseline engine and the current production engine is shown above.

In-Line Engine Configuration



The typical 100:1 overall pressure ratio engine that resulted from the studies consists of a two-spool geared configuration with a bypass ratio of 20 to 25. The resulting fan pressure ratios are 1.3 to 1.4. Low drag nacelles are required to minimize the losses associated with the high bypass ratios. Efficiency improvements are needed in both the compressor and the turbine to enable thermal efficiency improvements at the higher pressure ratio. Advanced materials such as ceramic matrix composites (CMC) and intermetallic matrix composites (IMC) are used extensively throughout the hot section of the engine to reduce or eliminate cooling flow requirements. Since the fan must be geared to achieve the very high bypass ratios, advanced gearbox technology will be needed to achieve the required transmission power of about 50 000 hp. As a result of the high overall pressure ratio, the combustor entrance pressure and temperature are very high. This would result in NO_x formations exceeding current levels with current technology combustors. Therefore, NO_x combustor technology must be developed for very small combustors in this type of engine.

Subsonic Transport Engine Results



BPR:	20 - 25	17 - 25	10
OPR:	~100	~75	75
FPR:	1.3 - 1.4	1.3 - 1.4	1.6
Fan type:	Geared	Geared	Direct
T_{4max}/Material:	~3200 °F/CMC	~3000 °F/ Cooled CMC or IMC	3200 °F/CMC

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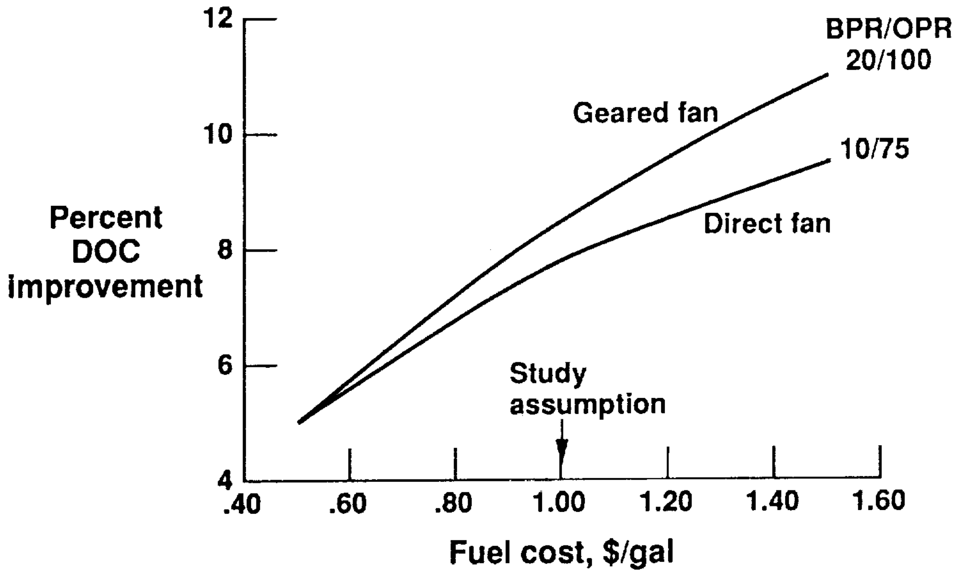
Reductions in fuel usage of 19 to 28 percent and in direct operating cost of 6 to 14 percent were projected for the advanced study engines. The shaded bands represent a range of cycle and technology assumptions. A geared engine with a very high bypass ratio of 20 to 25, overall pressure ratio near 100, and a turbine inlet temperature of 3200 °F resulted in a fuel savings of approximately 25 percent and a DOC improvement of nearly 10 percent. Limiting the hot section temperature to 3000 °F (assuming a less aggressive turbine material technology), resulted in a fuel savings greater than 20 percent and a DOC improvement near 10 percent. Finally, with a direct (non-geared) fan, the bypass ratio limited to 10, and an overall pressure ratio of 75, fuel savings were near 20 percent and the DOC improvement approached 10 percent.

Impact Of Fuel Cost On DOC



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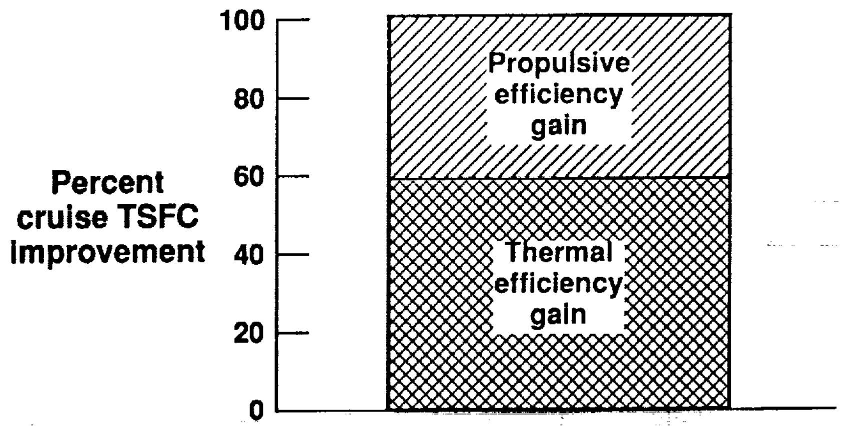
World fuel prices are very volatile and will likely remain so. The cost of fuel can have a dramatic effect on the direct operating cost realized with high-efficiency cores. For example, a threefold increase in fuel cost yields a twofold improvement in DOC. This is a result of the fuel price becoming a larger percentage of DOC.

The future fuel cost may also have an effect on the engine configuration that is most cost effective. At low fuel costs there is little or no benefit for a geared fan engine in terms of DOC. The higher initial cost and higher maintenance cost outweigh the lower fuel consumption. However, at the study assumption of $1.00/gal, there is a small benefit shown for the geared fan configuration. This benefit continues to increase as the fuel costs increase. Thus, fuel prices well above $1.00/gal may require the development of the technologies associated with geared fan engines.

Performance Improvement Breakdown



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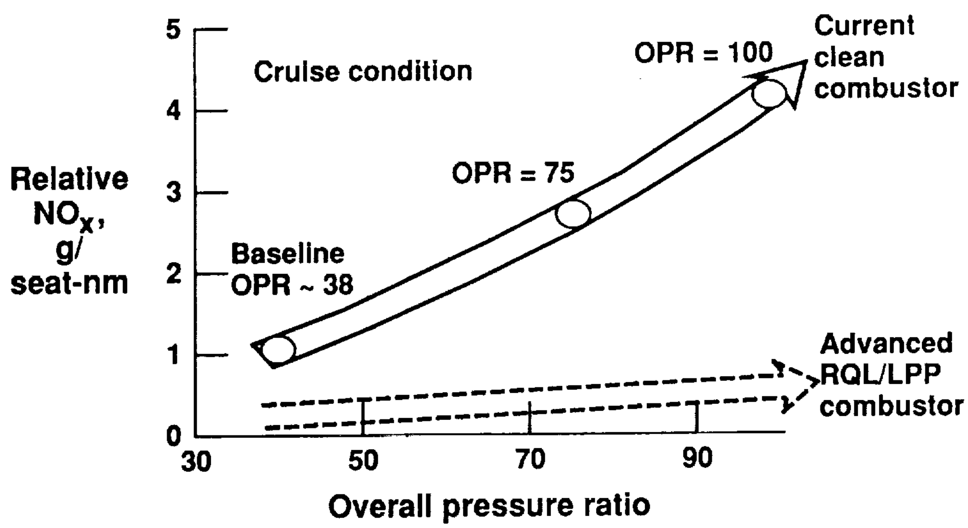
The combination of increased pressure ratio, improved core component efficiencies, and advanced materials that allow higher turbine temperature with reduced cooling flow directly provide a thermal efficiency gain that accounts for about 60 percent of the overall performance improvement. These same advanced core materials and improved core components provide the increased core specific power that enables a large part of the propulsive efficiency gain through the use of higher bypass ratios. Low drag, thin nacelles, and improved low-spool component efficiencies provide the remainder of the propulsive efficiency gain.

Engine Emissions Challenge



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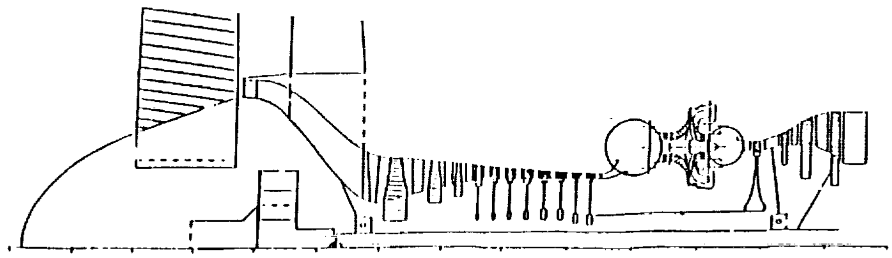
One of the challenges resulting from the use of the high-pressure-ratio cores is a reduction of NO_x emissions. As the pressure ratio is increased, the combustor entrance pressure and temperature increase. The severe combustor entrance conditions produce very high NO_x emissions compared to the baseline configuration, even when fuel savings are included. These high emissions can potentially be reduced to levels at or below those found in the baseline through the use of rich-burn/quick-quench/lean-burn (RQL) or lean-premixed-prevaporized (LPP) combustors which are being developed under the High-Speed Research (HSR) program. However, the combustor required for the high-pressure-ratio subsonic engine is an order of magnitude smaller in airflow size compared to the HSR combustor. Therefore, additional work may be required to develop the RQL and LPP technology for such small combustors.

Unconventional Core Engine



Potential Benefits of Off-Axis Core

- **Reduced component losses**
- **Lower part count**
- **Core reliability**
- **Ease of maintenance**

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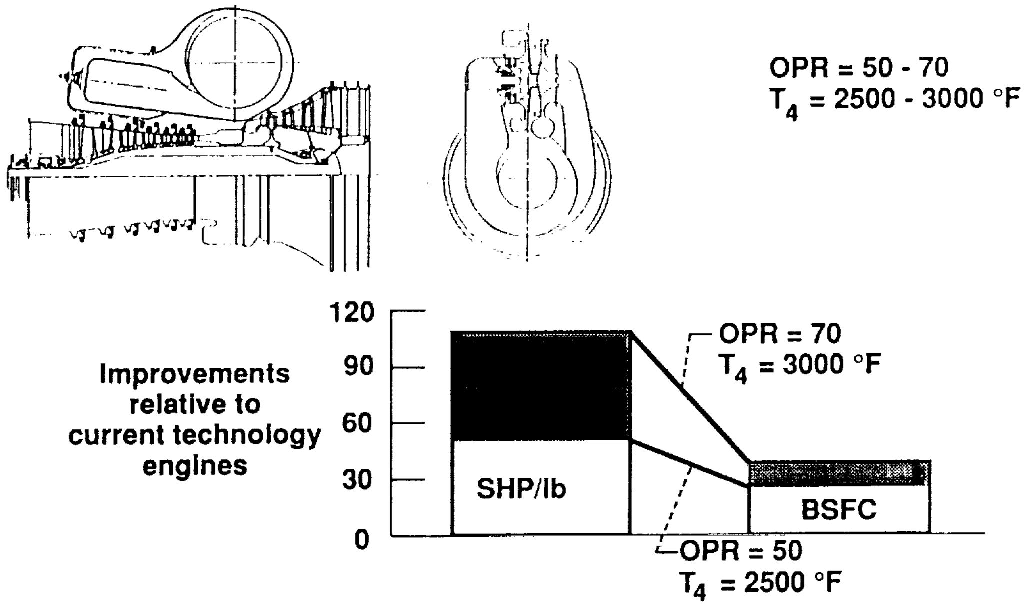
A conventional in-line engine with a very high pressure ratio has small compressor stages leading to potentially significant aerodynamic losses and mechanical design problems. An alternative under consideration is to duct the flow to one or more cores that are off-axis from the main engine. Because an off-axis core does not have a fan or low-spool shaft running through it, the hub diameter can be reduced. This adds design flexibility to the high pressure spool so many of the aerodynamic and structural penalties from small sizes in an in-line configuration can be avoided. Also, since centrifugal compressor and radial in-flow turbine stages are feasible in an off-axis configuration, the parts count can be reduced compared to a conventional all axial configuration. If multiple off-axis cores are used, there is redundancy in the hot section which could potentially increase reliability. Hot section maintenance could also be simplified because the low pressure spools would not have to be removed for access to the high pressure spool. Such an off-axis arrangement is being evaluated as part of a follow-on study.

Small Engine Study

8000 SHP



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Allison undertook a study to assess the benefits of advanced high-efficiency cores for an 8000-SHP turboshaft engine relative to a current technology engine. All performance improvements were evaluated in terms of engine parameters. Because of the small size of the engine in this study, an off-axis core configuration was the only viable design to result from the investigation. The design arrangement had the core axis 90 degrees to the main axis of the engine. Two levels of technology were assumed. The first design assumed a hot section material temperature limit of 3000 °F, which resulted in an optimum overall pressure ratio of 70. The second design assumed materials that were only capable of 2500 °F, which resulted in an overall pressure ratio of 50. The two levels of technology are shown as bands on the figure. The study projected a potential brake specific fuel consumption (BSFC) reduction of more than 30 percent with a specific weight improvement of 50 to 100 percent.

High-Efficiency Core Summary

- High-efficiency cores have potential for large fuel savings and DOC improvements for both large turbofan and small turboshaft engines. For large subsonic transport engines these improvements are
  - 19 - 28 percent fuel savings
  - 6 - 14 percent DOC

  at a fuel cost of $1.00/gal.
- Improvements result from high cycle pressure ratios, enhanced component efficiencies, and advanced materials.
- Advanced materials allow high temperatures without severe cooling penalties and thus enable the high specific power needed for bypass ratios of 10 to 25.
- Advanced combustor technology is needed to meet the emissions challenge in small size combustors.
- Off-axis cores lead to substantial improvements for small size engines and may have potential benefit on the large size engines.

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The advanced high-efficiency core study engines with an entry into service date of 2015 have the potential for large fuel savings and DOC improvements for both large turbofan and small turboshaft engines. The fuel savings resulting from the large subsonic transport engines were 19 to 28 percent when compared to a proposed next-generation turbofan engine with an entry into service date of 1993. The corresponding DOC improvements are 6 to 14 percent for a fuel cost of $1.00/gal. These improvements result from high cycle pressure ratios, high bypass ratios, enhanced component efficiencies, and advanced materials. The advanced materials allow high temperatures without severe cooling penalties and thus enable the high specific power needed for bypass ratios of 10 to 25.

The small component sizes associated with high pressure engines create new challenges, such as controlling emissions and minimizing aerodynamic losses in turbomachinery. Advanced combustor technology is needed to meet the emissions challenge. Also, unconventional off-axis cores, which lead to substantial improvements for small size engines, may also have potential benefit on the large size engines. Studies are currently underway to investigate the potential benefits of off-axis cores in large engines.